HYDRAULIC GRINDING OF SORGHUM GRAINS IN THE PREPARATION OF STARCHES

by

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B. S., Kansas State College
of Agriculture and Applied Science, 1948

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Chemical Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1951

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INTRODUCTION

For centuries sorghum has been an important food grain in many foreign countries, yet it has remained almost unused for that purpose in the United States. It was grown as early as 700 B.C. in Assyria and was a main source of cereal, the nutritive value of which compared favorably with other grains. Although it has been replaced to a great extent in Western Europe by cereals more bland and mild of taste, sorghum together with millet remains a main source of the "poor man's" cereal in many parts of Europe, Asia, and Africa. Considering that its use in these countries is essentially as food, it is interesting to note the comparison of production of sorghum with wheat and rice. For the period of 1934-1938, the average production of sorghum was 50,300,000 short tons a year as compared to 171,000,000 of wheat and 110,300,000 of rice (1).

In this country the principal use has been for stock feed and was never really exploited as a cereal. Early cursory inspections of its possibility as a raw material for starch showed little promise. Approximately 70 per cent of our domestic needs were supplied by the corn starch industries and the remainder by cheap, duty free tropical starches (2). They were well established and had a more than ample supply of raw materials. However, with the ebb of the depression came the realization of the importance of seeking additional industrial uses for other farm products. The sorghums had long been considered an ideal crop because of their ability to withstand the prolonged periods of hot, dry weather found in the

regions of the Great Plains. They could be planted later than most crops and their stubble held well to the soil, deterring wind erosion. Possessing these desirable growth characteristics and hardiness, the sorghum grains presented an ideal, dependable source of raw materials for the starch industries.

In 1937 the Kansas State Agricultural Experiment Station began an investigation of the utility of these grains with the view of eventual economic contributions that would be made if the grain could be utilized industrially (3). More recently the Kansas Industrial Development Commission has sponsored a series of projects at Kansas State College to study the difficulties encountered in preparing products from the sorghum grains. During World War II the need for producing starches from materials other than corn was felt when circumstances made it extremely difficult for the manufacturers to obtain ample supplies. As a consequence, the starch industry was forced on a few occasions to resort to other starchy grains such as wheat and sorghum (4). The same procedures used in the production of starch from corn were tried with sorghum, but the results were not satisfactory (5). It is interesting to note that in the period 1934-43, 5,000,000 acres were planted in the United States producing 70,000,000 bushels while in 1945 over 7,000,000 acres were planted and the crop was over 96,000,000 bushels (6).

The grain itself, when utilized industrially, can produce starch, edible and non-edible oils, and stock feeds. The starch is the principal constituent, accounting for about 70 per cent of

the weight, while the oils and stock feed are necessarily classified as by-products. There are two basic fields of application for the starch, in chemical conversion and in its natural or slightly modified forms. The starch for the latter use finds its way to the market for a variety of purposes in other industries as well as on the consumers' market.

In earlier projects the starch was recovered from the sorghum endosperm by operations quite similar to those used in the corn starch industries. A study was made of the various factors that affected the rate of diffusion in the steeping of the grains since the make-up of the sorghum kernel is quite different from the corn kernel (7). This difference necessitates different steeping times and temperatures for the different grains and is of importance in the quality and yield of the starch. Starches were actually produced from the sorghums on a small scale in operations quite similar to the corn starch industry (8). Since the scale was small, it was felt that operations on a larger scale would give better yield data.

The primary purpose of this project, which was sponsored by the Kansas Industrial Development Commission, was to produce starch in larger quantities with special emphasis on yield data. It was recognized that the method of grinding was one of the most important factors affecting the yield. The ideal method would be one that separated the starch from the gluten and fiber in such a manner that granules of relatively the same size were produced. This would enhance the possibilities of a sharp separation on the starch tables. Unfortunately, in the use of the buhrstone mill (widely used in the

corn starch industry), the endosperm is exposed to the positive shearing action of the mill. This results in heating of the grain, accompanied by agglomeration or coalescence, and results in irregular particle sizes extending to both extremes. This gives rise to difficulties in separation of the starch from the gluten. It was felt that if the grinding were performed by some mechanism other than the positive shearing action of the buhrstone mill, a more uniform starch granule might be obtained which would result in increased yields and higher quality.

Of collateral interest was the possibility of improving the quality of the starch. Generally speaking, the problem of obtaining a starch of good quality is one of separating the starch granules from the gluten matrix in which they are imbedded in the endosperm. Modern practice in corn starch milling uses the buhr-mill to separate the granules from the fiber. The resulting "starch milk" is either passed through high speed centrifuges to separate the gluten from the starch, or passed over long sloping, flatbottomed troughs, called tables, where the starch settles out while the gluten stays in suspension. However, there are certain problems that arise from the grinding that cannot be totally corrected by the most efficient means of separation. It has been shown that in the cracking of the whole grain, methods that used compressing or shearing action were not desirable since they caused the oil to be expressed from the germ and contaminated the endosperm (9). In the separations that precede the grinding of the endosperm it is difficult to remove all of the hulls and germ

and as a result there are small amounts present in the grits, these amounts varying with the efficiency of preparation. When the grits are ground, these small particles are mixed into the starch particles, causing slight contamination. Any method that would remove this deficiency would necessarily increase the quality of the starch.

The problem of contamination of the starch granule during separation from the whole grain has been eliminated to a great extent by a dry milling operation developed by Dr. H. Barham. In this operation the hulls are removed from the bran by abrasion and the debranned grain cracked by impact milling. In this manner the starch granule is prepared with a minimum use of positive shearing action.

EQUIPMENT

Preliminary to designing the hydraulic mill, laboratory scale investigations were made using a Waring blender as a mill. The Waring was chosen since it operated on principles similar to those under consideration for the design of the hydraulic mill. Using small quantities of grits with short grinding periods, yields between 40 and 55 per cent were obtained. The starches produced separated sharply from the gluten and were average in quality.

In selecting the capacity of the mill, it was felt that it should be capable of handling at least 10 pounds of the grain with sufficient amounts of water to keep the grain in motion. These amounts would require a volume of about one to one and one-half

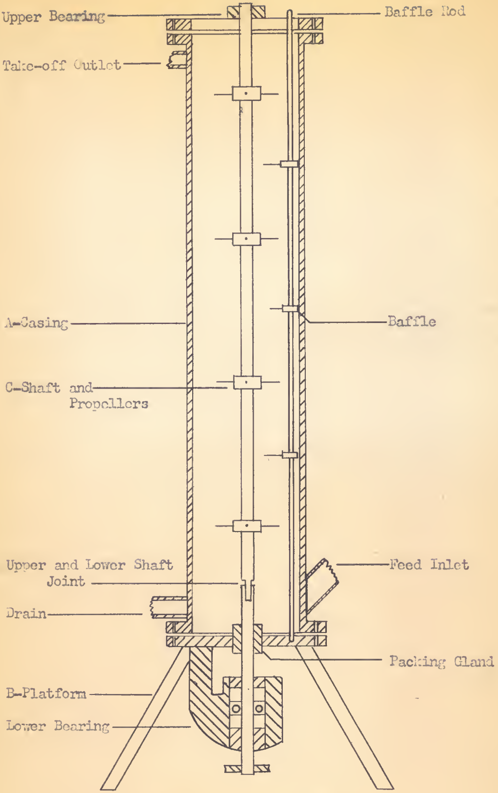
cubic feet. It was felt that by using a circular casing for the original tests the value of the shape factor could be later determined in variations of the design.

Plate I shows a sketch of the original design. The mill itself consisted of three major sections; the casing (A), the support (B), and the turbulence mechanisms (C). A three foot section of six inch standard iron pipe was used for the casing. A flange was welded to the bottom to provide for attachment to the support unit with bolts. This allowed for simplicity of disassembling. A flange was also welded to the top for mounting of the top centering bearing and securing the baffle rods. A one and one-half inch nipple was fitted at 45° F. about two inches from the bottom as the feed pipe. Additional half inch nipples were fitted at the top and bottom of the casing. A small gear pump was installed between these nipples to circulate the slurry from the bottom to the top of the mill.

The support section consisted of the mill platform and a lower bearing support. The propeller shaft was made in two parts; the upper propeller shaft was readily removable and the lower shaft was permanently assembled in the bottom plate assembly as shown in Plate I. This insured against leaks and excessive wear on the lower bushings and bearings. Power was provided to the lower shaft by a 10 horsepower constant speed motor through a V-belt and sheaves, and a watt-meter was placed in the line to provide direct readings of the power consumed. The speed of the shaft was varied by changing

EXPLANATION OF PLATE I

A cutaway view of the starch mill designed for the hydraulic grinding of sorghum endosperm.


Upper Bearing
Baffle Rod
Take-off Outlet
A-Casing
Baffle
C-Shaft and
Propellers
Upper and Lower Shaft
Joint
Feed Inlet
Drain
Packing Gland
B-Platform
Lower Bearing

sheaves on either the motor or propeller shaft.

The turbulence mechanisms consisted of a system of propellers and baffles. The double-bladed propellers were ground in such a manner to provide an upward thrust. They were attached to the shaft by set screws and could be removed or their number increased as desired. The baffles were mounted on four rods that fitted into recesses into the support platform and were held in place by bolts on the upper end. The rods were arranged symmetrically about the casing wall. The baffles were removable and were ground to provide a downward thrust.

A feed hopper was made and installed on a platform above the mill to provide continuous and uniform feed. The mixture of water and grits was fed from the hopper to the mill by a screw-feeder. It was powered by a quarter horsepower motor with a variable speed pulley drive, and the rate of feed could be varied from 1/8 to 3/4 of a pound of grits a minute.

The mill was designed to operate at shaft speeds up to approximately 3,000 RPM. The equipment for steeping the grits, the wet gravity tables for separating the starch and gluten from the fiber, and the starch tables were not designed or built for this particular project, but were available from previous studies, and were used with only such modifications as the larger volumes necessitated.

Fig. 1. Hydraulic grinding mill completely assembled.

Fig. 2. Hydraulic grinding mill without the casing.

PROCEDURE

Preparation of the Grits

Preliminary to the actual preparation of the starch, the endosperm (referred to hereafter as "grits") was prepared. Westland Milo sorghum was used for the investigation. The grain was first debranned in 20 pound batches. The grain was tempered with 2½ pounds of water for 15 minutes and bran (hulls) removed by five passes through the debranner. The bran and grain were then dried in a tray drier at 120° F. until the moisture content was reduced to between 10 and 12 per cent. The grain and bran were then aspirated to remove the bran and the debranned grain cracked in an entoleter, an impact mill manufactured by the General American Transportation Company. The cracked grain was placed on a vibrating screen and the cut between the 20 and 30 mesh screens collected and aspirated. The final separation of the grits from the germ was made on an Oliver separator. By careful preparation an endosperm fraction with a minimum of germ and bran was obtained. This fraction, called grits, was stored in steel drums with locking lids and fumigants to prevent insect infestation.

Producing the Starch

Steeping. The size of the batch was determined arbitrarily at 10 pounds of grits. The grits were mixed with 25 gallons of water and steeped in a steel vat fitted with hot-water coils for two hours at a constant temperature of 130° F. with continuous

agitation by a propeller-type mixer. Steeping time was taken from the start of the heating cycle.

Grinding. In the grinding there were three main variables to be considered: the speed of the propeller shaft, the time of grinding, and the size of the load. Originally it had been planned to make the operation a continuous one and vary the rate of feed. However, from the outset certain difficulties encountered made the results incapable of accurate evaluation. For instance, as the starch milk was drawn off at the top, quantities of unground grits were drawn off. By screening they could be returned and ground, but this interfered with feed rates and placed some grain in contact longer than the others. It was therefore decided that by dividing a run into loads of varying sizes, the grain could be held in contact for the determined length of time and then drawn off and this repeated until the entire 10 pounds of grits were ground. Loads were set at $1\frac{1}{4}$, $2\frac{1}{2}$, 5, and 10 pounds. When the grain was drawn off from steeping, it was divided into the required number of loads and made up to from 1 to 8 gallons with steep water, depending on the batch sizes.

The load size, time of grinding, and shaft speed were set for each run. Half of the steepwater required for the mill load was placed in the mill and the circulating pump and drive motor were started. The grits and the remainder of the water were poured in. When the predetermined time had expired the mill was stopped and the slurry drawn off and the power consumed recorded.

The same operation was repeated until the 10 pounds of grits had been ground. This operation was repeated with the same load size and shaft speed for grinding times per load of 5, 10, 15, 20, and 30 minutes. The same procedure was repeated for the remaining load sizes. This gave a fairly complete picture of the effect of time and load size on one particular shaft speed. Shaft speeds of 1800, 2300, and 2600 RPM were investigated. Since it was not practical or necessary to completely repeat this procedure for all three shaft speeds, only sufficient runs at the remaining speeds were made to give a comparison between the shaft speeds. Where the yields were so low to be of only comparative value, the entire series was not run, and only enough data were taken to make usable graphs. In all, over 60 recorded runs were made.

In making the runs, it was sometimes necessary to allow the slurries to stand overnight or to allow the starches to remain on the tables. Usually fermentation took place by morning because of the presence of the nitrogenous materials and the excessive heat. This was decreased to a considerable extent by a slight change in procedure. Instead of grinding the grain in the steep water, the steep water was drained off, the grain washed, and then ground in clear water of the same temperature of the steep. While this would be impractical and costly in industry, it was merely an expedient chosen to meet a problem not present in industry. The losses of the solubles in the steep water were small and did not noticeably affect the yields, but the change did seem to improve the color

slightly. A coil of copper tubing was also placed in the slurries when kept overnight, and tap water circulated through them in order to keep the temperature as low as possible.

In all of the above mentioned runs the number of baffles and propellers remained the same and the temperature of the water varied but a few degrees. However, a few runs were made with the baffles completely removed to determine their effect. Several runs were also made without external circulation, and other runs were made using make-up water of 70° F. instead of 120° F.

Treatment of the Slurry. When the slurry was drawn off, it was screened through a 200 mesh stainless steel vibrating screen. The screenings were collected and dried for 8 hours at 130° F. and the weight recorded and samples taken. The starch milk, composed of the starch, water, and gluten, was thoroughly mixed and its temperature and specific gravity recorded. It was then pumped on the starch tables at a constant rate of $\frac{1}{2}$ gallon per minute. When the tabling was completed the starch was washed and removed from the tables. It was dried for 4 hours at 130° F., weighed and samples were taken for further analysis.

DATA

In Tables 1, 2 and 3 are recorded experimental data for all runs made under the standard conditions set in the procedures. That is, these tables include only those runs in which the turbulence mechanism was identical, circulation was used, and the grain was ground either in steep water or in make-up water of 120° F.

In Table 4, the experimental results are recorded where the standard grinding conditions as described in the procedure are used with the exception that circulation was not provided.

The data shown in Table 5 were obtained by grinding the grits with make-up water of only 70° F. as compared with the standard of 120° F.

Table 1. Data on grinding of 10 pound batches at shaft speed of 2600 RPM.

Run no.	Loads per batch	Pounds per load[1]	Grinding time per load (min.)	KWH per batch	Starch yield per batch (lb.)	Percent yield starch	Screening per batch (lb.)	Percent yield screening	Temp. make-up water (°F.)
38	8	1.25	10.0	1.25	3.19	31.9	4.68	46.8	120
40	4	2.5	5.0	0.3	1.88	18.8	4.75	47.5	120
39	4	2.5	10.0	0.7	2.75	27.5	4.28	42.8	120
41	4	2.5	20.0	1.25	3.38	33.8	3.25	32.5	120
30A	4	2.5	30.0	1.3	3.56	35.6	2.63	26.3	120
34A	2	5.0	10.0	0.3	2.45	24.5	4.5	45.0	120
43A	2	5.0	20.0	0.7	3.0	30.0	3.5	35.0	120

[1] In each run a 10 pound batch of grain was ground. The batch was divided into the required number of loads of equal weight. The load size represents the actual amount of grain in the mill.

Table 2. Data on grinding of 10 pound batches at shaft speed of 2300 RPM.

Run no.	Loads per batch	Pounds per load[1]	Grinding time per load (min.)	KWH per batch	Starch yield per batch (lb.)	Percent yield starch	Screening per batch (lb.)	Percent yield screening	Temp. make-up water (°F.)
23	8	1.25	5.0	0.7	3.95	39.5	3.49	34.9	120
51	8	1.25	10.0	1.4	4.25	42.5	2.99	29.9	120
25	4	2.5	5.0	0.4	3.51	35.1	3.98	39.8	120
54	4	2.5	10.0	0.7	3.85	38.5	3.50	35.0	120
45	4	2.5	20.0	1.4	4.15	41.5	2.57	25.7	120
42	4	2.5	30.0	2.1	4,00	40.0	2.74	27.4	120
52	2	5.0	5.0	0.3	3.00	30.0	4.31	43.1	120
50	2	5.0	10.0	0.2	3.40	34.0	3.99	39.9	120
16A	2	5.0	20.0	0.4	3.80	38.0	3.15	31.5	120
47A	2	5.0	30.0	1.2	3.75	37.5	2.03	20.3	120
19A	1	10.0	5.0	0.2	2.80	28.0	4.75	47.5	120
53	1	10.0	10.0	0.4	2.95	29.0	4.35	43.5	120

[1] In each run a 10 pound batch of grain was ground. The batch was divided into the required number of loads of equal weight. The load size represents the actual amount of grain in the mill.

Table 3. Data on grinding of 10 pound batches at shaft speed of 2600 RPM.

Run no.	Loads per batch	Pounds per load[1]	Grinding time per load (min.)	KWH per batch	Starch yield per batch (lb.)	Percent yield starch	Screening per batch (lb.)	Percent yield screening	Temp. make-up water (°F.)[2]
6	8	1.25	5.0	1.4	4.0	40.0	3.25	32.5	
7	8	1.25	10.0	3.0	5.25	52.5	2.75	27.5	
9	8	1.25	10.0	3.0	5.3	53.0	2.75	27.5	
8	8	1.25	15.0	4.2	5.51	55.1	2.05	20.5	
49	8	1.25	20.0	3.1	5.45	54.5	1.51	15.1	120
11	8	1.25	30.0	4.2	5.3	53.0	1.0	10.0	
10	4	2.5	5.0	0.7	3.6	36.0	3.56	35.6	120
12	4	2.5	10.0	1.5	4.4	44.0	3.0	30.0	120
24[3]	4	2.5	10.0	1.4	2.06	20.6	4.25	42.5	120
13	4	2.5	15.0	2.2	5.0	50.0	2.38	23.8	120
22	4	2.5	20.0	2.95	4.92	49.2	2.0	20.0	120
46	4	2.5	30.0	4.1	4.75	47.5	1.13	11.3	
15	2	5.0	5.0	0.35	3.39	33.9	3.85	38.5	120
16	2	5.0	10.0	0.63	4.0	40.0	3.25	32.5	120
14	2	5.0	15.0	1.3	4.51	45.1	2.65	26.5	120
17	2	5.0	20.0	1.23	4.39	43.9	2.13	21.3	120
47	2	5.0	30.0	2.1	4.3	43.0	1.63	16.3	120
19	1	10.0	5.0	0.2	3.0	30.0	4.13	41.3	120
20	1	10.0	10.0	0.35	3.38	33.8	3.44	34.4	120
21	1	10.0	15.0	0.5	3.89	38.9	2.92	29.2	120
18	1	10.0	20.0	0.7	3.8	38.0	2.38	23.8	120
48	1	10.0	30.0	0.1	3.8	38.0	2.0	20.0	120

[1] In each run a 10 pound batch of grain was ground. The batch was divided into the required number of loads of equal weight. The load size represents the actual amount of grain in the mill.
[2] If ground in steep water, no make-up water used.
[3] No baffles used.

Table 4. Data on grinding of 10 pound batches without the use of circulation.

Run no.	Loads per batch	Pounds per load[1]	Grinding time per load (min.)	KWH per batch	Starch yield per batch (lb.)	Percent yield starch	Screening per batch (lb.)	Percent yield screening	Temp. make-up water (°F.)	Shaft speed (RPM)
33	8	1.25	10.0	1.2	1.06	10.6	6.56	65.6	120	1800
35	4	2.5	10.0	0.65	1.83	18.3	5.63	56.3	120	1800
34	2	5.0	10.0	0.35	2.0	20.0	5.81	58.1	120	1800
28	8	1.25	10.0	2.65	2.31	23.1	3.75	37.5	120	2600
29	4	2.5	10.0	1.4	2.75	27.5	3.88	38.8	120	2600
26	2	5.0	10.0	0.6	2.94	29.4	3.94	39.4	120	2600
27	1	10.0	10.0	0.35	3.06	30.6	3.84	38.4	120	2600
31	8	1.25	10.0	1.3	0.56	5.6	6.31	63.1	70	1800
32	2	5.0	10.0	0.3	1.56	15.6	6.06	60.6	70	1800

[1] In each run a 10 pound batch of grain was ground. The batch was divided into the required number of loads of equal weight. The load size represents the actual amount of grain in the mill.

Table 5. Data showing the effect of a decrease in temperature of grinding of 10 pound batches at 1800 RPM.

Run no.	Loads per batch	Pounds per load[1]	Grinding time per load (min.)	KWH per batch	Starch yield per batch (lb.)	Percent yield starch	Screenings per batch (lb.)	Percent yield screening	Temp. make-up water (°F.)
44	8	1.25	5.0	0.61	1.88	18.8	5.19	51.9	70
37	8	1.25	10.0	1.25	2.51	25.1	4.94	49.4	70
40A	4	2.5	5.0	0.35	1.75	17.5	5.25	52.5	70
36	4	2.5	10.0	0.65	2.38	23.8	4.94	49.4	70
43	4	2.5	20.0	1.29	3.00	30.0	3.75	37.5	70
32A	2	5.0	10.0	0.35	2.3	23.0	5.00	50.0	70

1 In each run a 10 pound batch of grain was ground. The batch was divided into the required number of loads of equal weight. The load size represents the actual amount of grain in the mill.

DISCUSSION

Starch yields up to 55 per cent were obtained in this investigation of hydraulic grinding of the endosperm. While these values fall short of necessary yields for economic commercial production, never-the-less a trend is indicated.

For the purpose of clarity the results will be discussed separately from the stand-point of the effect of shaft speed, time of grinding, load size, effect of temperature, and the effect of circulation.

Effect of Shaft Speed

While it was easily predictable that the starch yield would increase with the shaft speeds, it was hoped that an optimum speed could be reached. However, because of the design of the shaft, it was not considered safe to operate the mill at speeds in excess of 2600 RPM. Figure 3 shows increases in yields of from 10 to 20 per cent by increasing the shaft speed from 1800 to 2600 RPM for all four load sizes. By interpolation it will be noticed that the increase in yield by raising the shaft speed from 1800 to 2200 RPM is somewhat less than the corresponding increase in yield from 2200 to 2600 RPM. This would seem to indicate that the greater part of this study was operated far below optimum speeds.

An interesting point was noted with respect to the varying

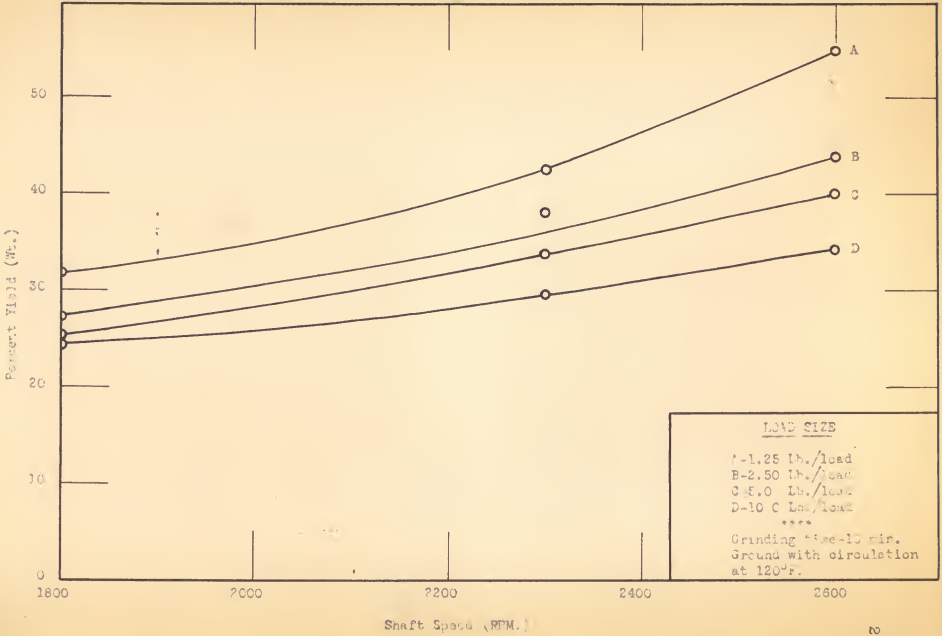


Fig. 3. The effect of shaft speed on starch yield at various load sizes.

shaft speeds. In operations at 1800 RPM, no matter what length of time the grits were ground or the size of the load, the temperature of the slurry remained fairly uniform. However, in runs at 2300 RPM a fairly uniform temperature rise of about 4° F. was noted while at 2600 RPM this rise was approximately 11° F. This temperature rise, like the yields, is greater in the upper ranges of the shaft speeds used. This would appear especially significant in future design. Undoubtedly, the temperature rise was caused in part by friction between the grain and the casing. From this it would seem that operations at higher speeds with possible variations in propeller and baffle design would enhance the yields.

Effect of the Time of Grinding

Probably the effect of the length of time of grinding was one of the most significant variables in this operation. In Figs. 4, 5, and 6, starch yield is plotted versus grinding time. Figure 4 shows only a trend of increasing yields with the increased time of grinding. However, the results of operations at higher shaft speeds, as shown in Figs. 5 and 6, give an indication of an optimum grinding time of approximately 20 minutes at 2300 RPM and 15 at 2600. The decrease in yield resulting from further grinding probably results from excessive size reduction of the more loosely held starch which has been released in the early stages of the grinding. The excessive grinding evidently reduces

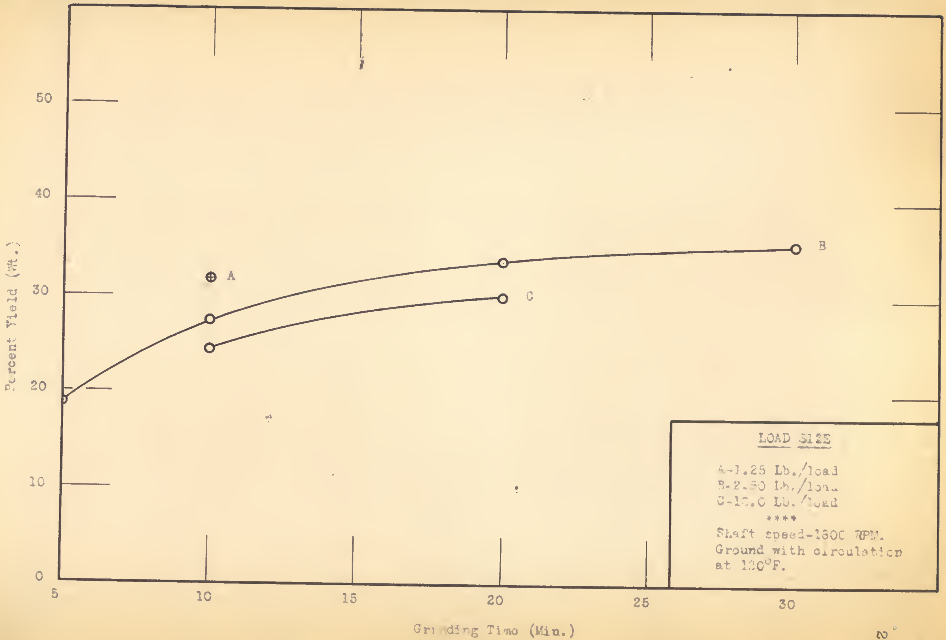


Fig. 4. The effect of grinding time on starch yields at various load sizes.

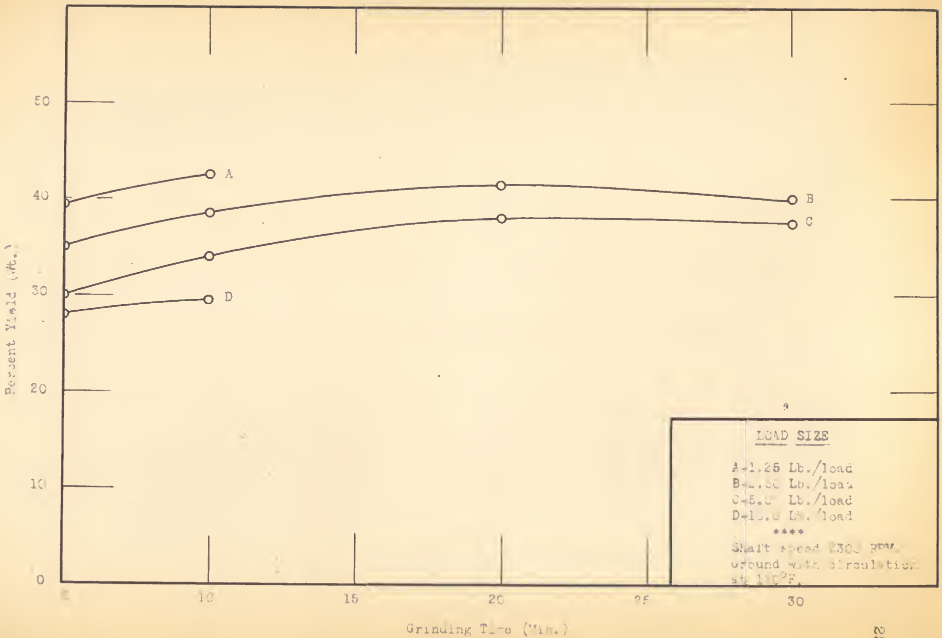


Fig. 5. The effect of grinding time on starch yields at various load sizes.

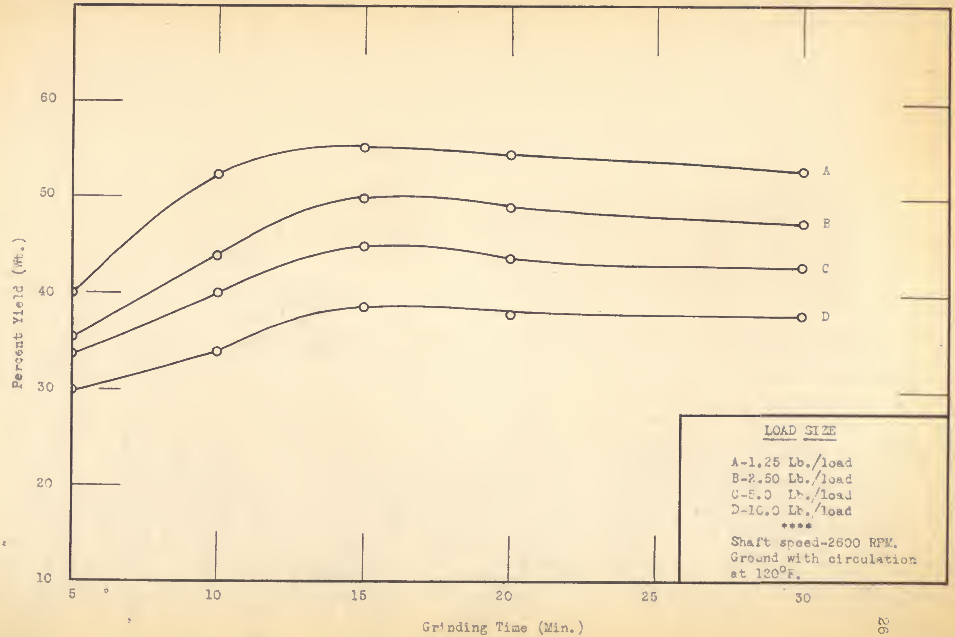


Fig. 6. The effect of grinding time on starch yields at various load sizes.

this first released starch to such an extent that some of it fails to settle on the starch tables and flows off. This could be cured in a continuous stage operation where, after grinding the optimum length of time, the slurry could be drawn off and screened and the screenings fed to another stage for further grinding. This would be repeated as often as might be required. Figure 7 shows by comparison the effect of grinding time on starch yields at the three selected shaft speeds.

The Effect of Load Size

These data merely serve to show the more efficient load sizes to use in this particular mill. Yet, while Fig. 8 would suggest that the smallest load was the most efficient, it should be remembered that in comparing these loads there is another factor to consider. The smallest load (1.25 lb.) takes eight times as long to grind the entire batch as the largest load (10 lb.). Therefore, in considering the various loads, the total grinding time should be kept in mind. By comparing the total grinding times, a true picture of the efficiency will be obtained. For instance, consider curve A in Fig. 9. In a total grinding time of 40 minutes, the 1.25 lb./load run produced 40 per cent starch. But curve B shows the 5.0 lb./load run taking a total grinding time of only 20 minutes and producing over 40 per cent starch, as well as the 2.5 lb./load run which used the same grinding time as the 1.25 load.

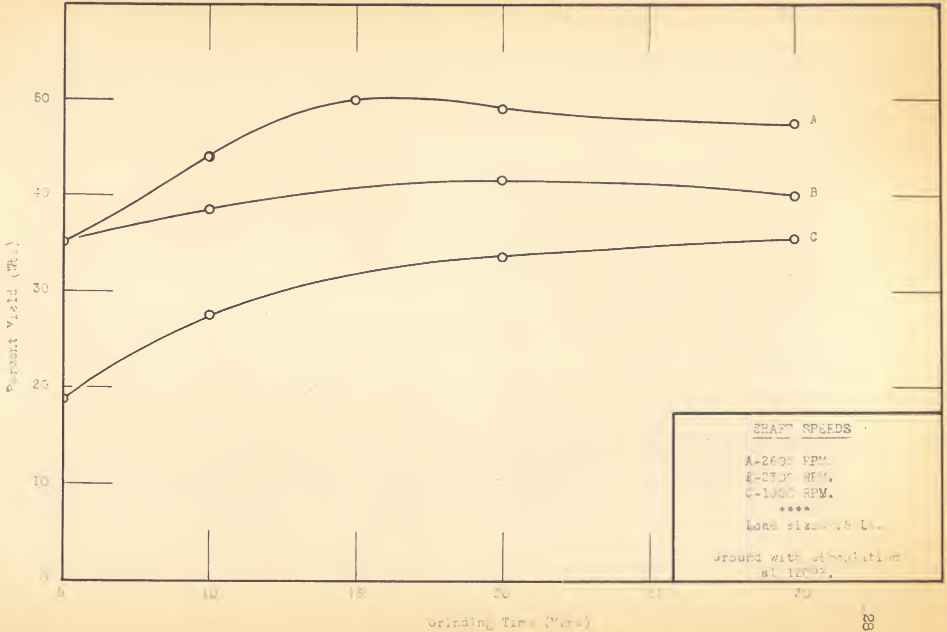


Fig. 7. The eff[illegible] of grinding time on [illegible] at [illegible] shaft speeds.

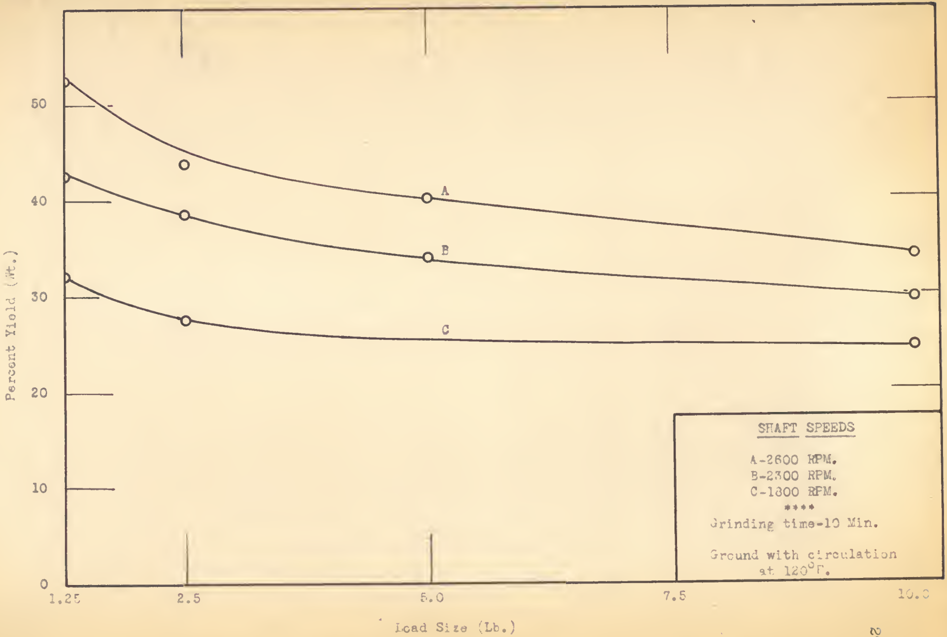


Fig. 8. The effect of load size on starch yields at various shaft speeds.

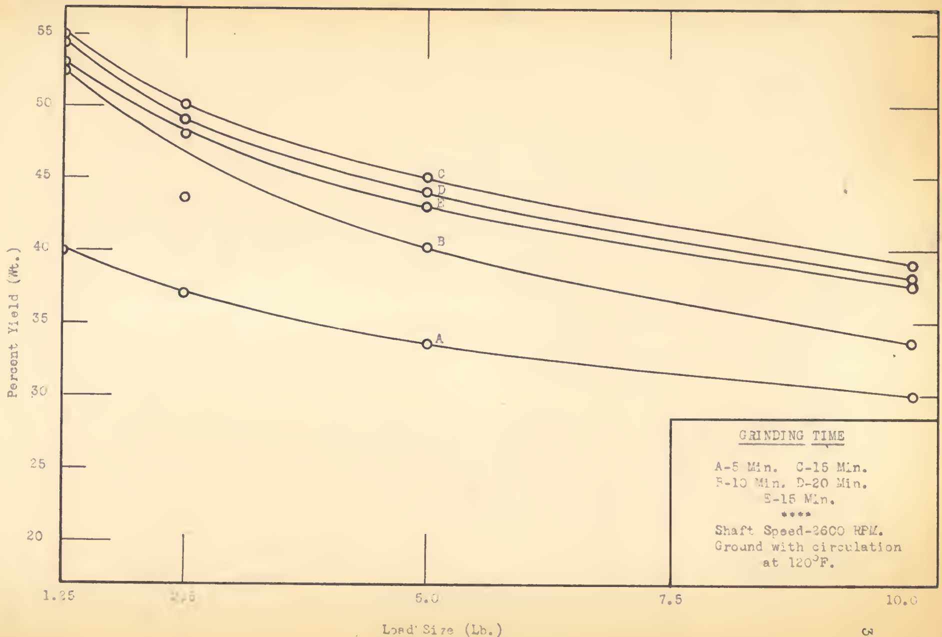


Fig. 9. The effect of load size on starch yields at various grinding times.

Also to be considered is the power consumed. For the most part, it can be said generally that the power consumption of the mill was fairly constant for the various loads, and varied almost directly with the total time of grinding. All of the above factors should be considered in deciding the mill load.

The slurry from the various loads was checked before screening, and observations were made of the shapes of the solids. At the two extremes of the load sizes two particle shapes were noted. In the smallest loads the particles tended to be flat and oval while in the larger loads they appeared nearly spherical. These shapes held true although the length of time of grinding and the shaft speeds were changed, the only difference being size of the particle. The only explanation for the difference in shape would be the increased intimacy of the grain in the larger loads. However, this observation together with the temperature observation leads to the conclusion that the grinding is being performed for the most part by abrasion of the grain with the casing and intergranular abrasion.

Effect of Temperature of Grinding

A series of runs were made using make-up water at 70° F. instead of 120° F. The results, shown in Fig. 10, indicate that reducing temperature to 70° F. resulted in lower yields.

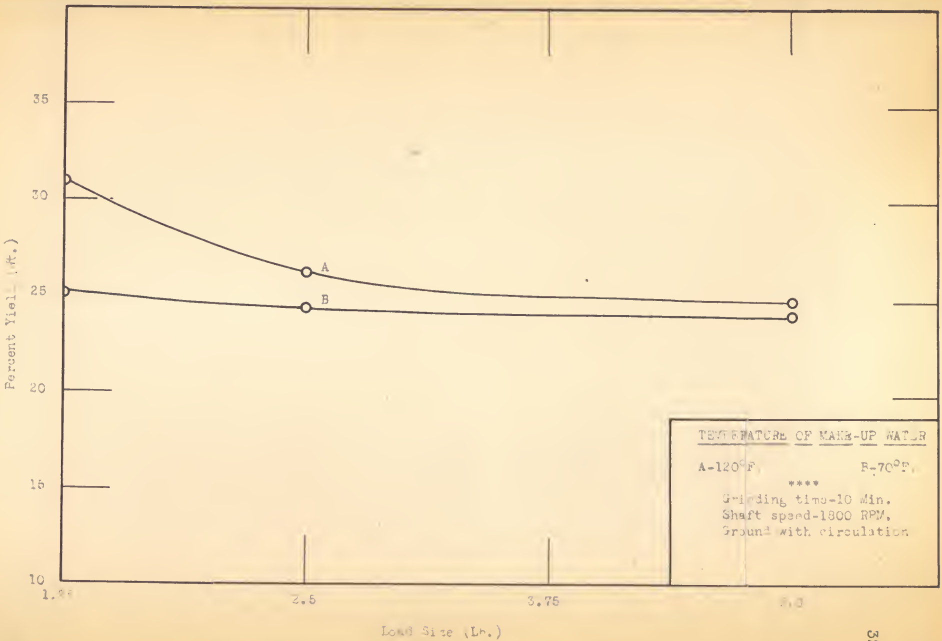


Fig. 10. The effect of a change in grinding temperature on the starch yield.

Effect of Grinding Without Circulation

A small gear pump was used to pump the slurry from the bottom of the mill to the top. Before using the pump, slurry was run through the pump to determine what grinding, if any, took place in the pump. The maximum amount of starch produce by the pump in the longest periods was 3 per cent and in the shortest runs only a negligible amount. Having determined that the pump itself contributed little to the starch yields by grinding action, it was removed for a series of runs to determine its contribution, if any, to the yield by added turbulence. The results as shown in Fig. 11 show quite clearly that it adds considerably to the yield. However, a correction in design would probably eliminate the need of the pump. There were no propellers in the bottom four inches of the casing, and a certain amount of grain settled there. As the load size increased the proportion of the load that settled was less thus accounting for the decrease in loss at the higher loads. By placing propellers at the bottom of the casing this condition would probably be eliminated.

SUMMARY

1. Substantial starch yields have been produced by hydraulic grinding of the sorghum endosperm, and the results indicate the method is a practical one.

2. Turbulence is the most important factor in the operation,

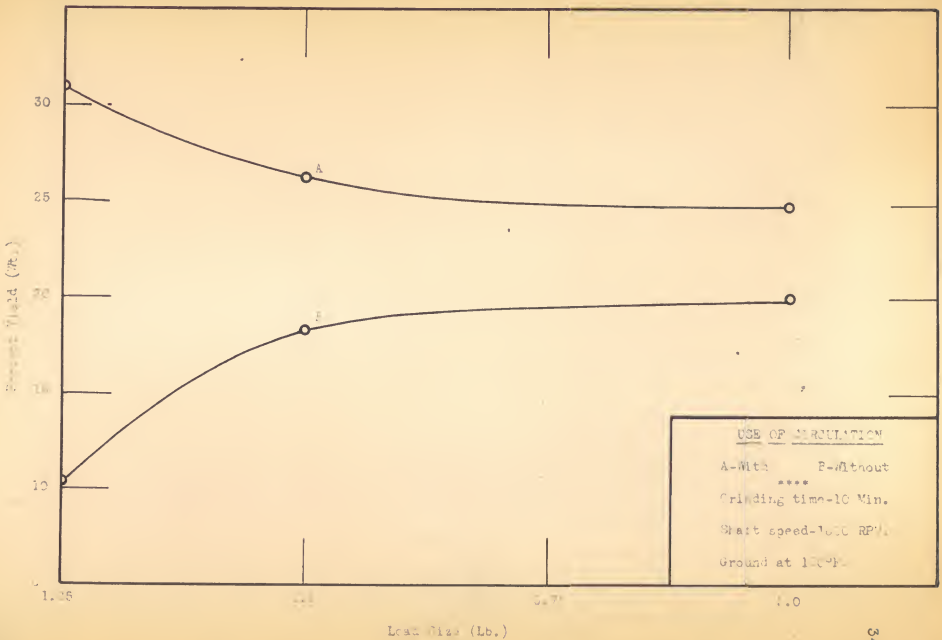


Fig. 11. The effect of varying turbulence mechanisms on the starch yield.

and the yields are directly related to it. The shape of the casing, pitch of the propeller and baffles, and the shaft speed are all factors to be considered in improving the yield.

3. The yield is decreased by excessive grinding.

4. While temperature need not be exactly controlled, decreases in grinding temperature to any great extent below 120° F. will result in lower yields.

ACKNOWLEDGMENT

The author wishes to express his appreciation to the Kansas Industrial Development Commission for making this study possible, and to Dr. H.T. Ward, Head of the Department of Chemical Engineering and to Mr. William H. Honstead, Associate Professor in the Department of Chemical Engineering, for their valued assistance and counsel.

REFERENCES

(1) Anderson, Elna, and John H. Martin.
World production and consumption of millet and sorghum. Economic Botany. 3:265-288, 1949.

(2) Hightower, J.V.
The new corn products plant: it makes wet-milling history. Chem. Engg. 56:92-96, 1949.

(3) Barham, Harold N., J.A. Wagoner, C.L. Campbell and E.H. Harclerode.
The chemical composition of some sorghum grains and the properties of their starches. Kansas Agr. Exp. Sta. Bul. 61. March, 1946.

(4) Slotter, Richard L., and Cecil T. Langford.
New techniques for wheat starch manufacture. Indus. and Engg. Chem. 36:404-408, 1944.

(5) Horan, F.E., and Marie F. Heider.
A study of sorghum and sorghum starches. Cereal Chem. 23:492-503, 1946.

(6) U. S. Department of Agriculture.
Crop reporting board, Bureau of Agr. Econ. Sept. 10, 1945.

(7) Long, Sam.
The effect of various factors on the rate of diffusion in steeping sorghum grains. Unpublished thesis, Kansas State College, Manhattan, Kansas, 1939.

(8) Johnson, Rodney.
The production of starch from grain sorghums. Unpublished thesis, Kansas State College, Manhattan, Kansas, 1942.

(9) Stewart, Robert H.
Impact grinding of sorghum grains. Unpublished thesis, Kansas State College, Manhattan, Kansas, 1947.

HYDRAULIC GRINDING OF SORGHUM GRAINS IN THE PREPARATION OF STARCHES

by

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B. S., Kansas State College
of Agriculture and Applied Science, 1948

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Chemical Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1951

The sorghum grains, long considered an ideal crop because of their sturdy growth characteristics, found little use as a raw product for American industry prior to World War II. However, the need for additional sources of raw materials in the starch industries to fulfill wartime needs resulted in the use of sorghum in small quantities. The inability to adapt existing operations to utilize the sorghum as a raw material prevented their large scale use. However, the possibilities were recognized and further study ensued.

The whole grain sorghum can be used to produce starch, edible and non-edible oils, waxes, and stock feeds. Starch is the principal constituent of the grain, being present in the range of 70 per cent by weight.

Previous experiments have been conducted on laboratory scale to obtain steeping data of the grain and properties of the starch. The primary purpose of this study, sponsored by Kansas Industrial Development Commission, was to produce larger quantities of starch with special emphasis on yield data. It was felt from the beginning that the grinding should be accomplished by mechanisms other than those utilized in the buhrstone mill. That is, the use of positive shearing action should be eliminated.

Preliminary studies on a laboratory scale using a Waring blender as a mill gave yields of 40 to 55 per cent starch of average quality and with a sharp separation of the gluten from the starch. The Waring blender was chosen because in grinding, the positive shearing pressure of the buhrstone was eliminated. The mill designed

and used throughout the study operated on similar principals. The casing was circular with propellar blades and baffles extending the length of the casing. The mill was designed to allow the grain to be ground in a liquid media and provided for various shaft speeds. The operation was by batch method.

The sorghum grain is not ground in the whole kernel. The hull (bran) is first removed and the debranned grain is cracked and separated into two fractions, the germ and the endosperm (hereinafter referred to as "grits"). The grits is the starch bearing fraction of the grain. Preliminary to grinding, the selected amount of grits was steeped at a constant temperature of 130° F. for two hours. The starch was then ground under varying conditions as to time of grinding, shaft speed, and size of the load. After grinding, the slurry was drawn off and screened on a 200 mesh stainless steel vibrating wet screen to separate the fiber from the mixture of the starch particles and gluten, referred to as "starch milk". The starch and gluten were separated by use of starch tables, a method in which the milk is allowed to flow at constant rates over horizontal tables, the starch settling while the gluten and water flow off.

The equipment, exclusive of the hydraulic grinding mill, was not designed for this particular project, but were available from previous studies and were used with only such modifications as made necessary to handle larger volumes.

Yields up to 55 per cent were realized in this investigation

of hydraulic grinding. An interpretation of the results shows that optimum shaft speeds were not reached. The maximum speed was limited, however, by the design of the shaft, and it was considered unsafe to operate at high speeds. It was noted that there was a sharp rise in temperature in the slurries at higher grinding speeds. Increasing the time of grinding resulted in increasing yields to a certain limit followed by a decrease in yield. This decrease in yield probably resulted from excessive size reduction of the more loosely held starch granules that were released in early stages of grinding. These smaller particles would be lost by failure to settle in the constant rate tabling. Variation of the load size gave no positive results other than the most efficient conditions at which the mill operated. However, a study of the particle shape size of the various loads, considered with observations of temperature rises at various speeds, is a further indication that there is considerable abrasive action.

The study indicates that turbulence is the most important factor and any factor that increases the turbulence. The shape of the casing, the pitch of the propellers and baffles, and the shaft speed are all factors to be considered in improving the yields.